RADIO-ACTIVE CHANGES IN THE EARTH.[1]

I WISH particularly to refer to manifestations of radio-activity which are observed, not in artificially prepared materials like radium, but in the rocks and minerals of the earth's crust, as we find them in nature. Let us consider, in the first place, the most conspicuous cases of this kind. The source from which radium is obtained is the mineral pitchblende. This mineral occurs in veins, like the majority of the useful metals; I may refer particularly to the mineral veins of Cornwall, so long famous as a source of tin. These veins are of the nature of cracks, running through the granite and through the slate which adjoins it. The cracks have been filled up by the various metallic ores which have been introduced by precipitation or sublimation, the exact nature of the process being somewhat obscure.

I will now show you an experiment, due to Sir W. Crookes, which illustrates the radio-activity of pitchblende in a very beautiful manner. A flat polished slab of pitchblende intergrown with a variety of other material which is not radio-active was laid face to face with a photographic plate, which was developed after the lapse of about a week of contact. The radium and other radio-active substances contained in the pitchblende have acted photographically upon the plate, while, of course, those portions of the material which are not radio-active have exerted no such action. Thus pitchblende has, as it were, taken its own portrait, which I now show you on the screen.

Pitchblende, the principal radium ore, contains, as you know, only an infinitesimal percentage of radium, the bulk of the substance being made up of oxide of uranium. Uranium is commonly spoken of as a rare metal; but terms of this kind are comparative only, and in contrast with radium, which is more than a million times scarcer, it seems common enough. Now I wish to speak for a little about this association of uranium and radium in pitchblende. Is it accidental, or has it some special significance? I hope to be able to convince you that it has.

In the early days of radium it was common to hear the difficulty emphasised that while there was no reason for doubting that the radium which was found in the earth had been there as long as other metals, a substance that was continually giving out energy in this way was obviously defying the greatest physical generalisation of the nineteenth century—the law of the conservation of energy. We cannot, however, afford to sacrifice this law so easily, and a ready mode of escape offers itself if we suppose that a continual waste of radium is occurring. In that case it becomes necessary to suppose, also, that the supply is in some way replenished, for otherwise all the radium would have wasted long ago. From what material are the fresh supplies of radium derived? They must be derived from some other substance contained in the mineral where the radium is found, and there is now reason to feel sure that uranium is the substance in question.

We have convincing proof of this in the fact that the amount of radium found in the mineral is always in direct proportion to the quantity of uranium which it contains. I should perhaps say, to avoid misconception, that there is good reason for believing that several transitional stages exist through which uranium passes on its road to become radium. It is not necessary, however, to take into account the existence of these intermediate products in order to form a clear idea of the process by which the supply of radium is kept up. Uranium changes spontaneously, though very slowly, into radium, and the amount of radium produced per annum, for example, will be proportionate to the amount of uranium present. On the other hand, a certain fraction of the total amount of radium present decays per annum, and the balance of this account of profit and loss will represent the amount of radium found in the mineral at any time that we examine it. There will be no difficulty in seeing that on this theory the amount of the radium in the mineral should be proportionate to the amount of uranium, and experiment fully confirms the theory by showing that such is in fact the case. We have here a clear and distinct case of the transmutation of metals, so long unsuccessfully searched for.

Let us now come back to the pitchblende.

What was the source of metalliferous ores found in mineral veins is a very much vexed question, and no solution of it which has yet been proposed can be said to be altogether free from difficulty. One of the most plausible theories, however, supposes that the metals have been derived from the rocks by which the veins are traversed. We are not here concerned with metalliferous ores in general, but only with those which carry radio-active material. In deciding whether the granite of Cornwall can be supposed to furnish the uranium of pitchblende, it is, of course, fundamental to know whether any uranium is present in the rock. It should be said, by way of preface, that the quantity must, at best, be very small, and certainly too small for detection by the methods of chemical analysis as ordinarily applied. We have seen that uranium in nature is invariably accompanied by a proportionate quantity of radium, and as it is in practice much easier to detect minute quantities of radium than to detect the corresponding quantities of uranium, it is best to look for the former only, and to be content to infer the presence of the latter.

I have made a large number of experiments to find out how much radium there may be, not only in Cornish granite, but in a large variety of other rocks. In every case the presence of radium has been established, though only to the extent of about one-millionth part of what is found in pitchblende, and even that, it will be remembered, is not much. If we take into account the very large bulk of the granite and the very small bulk of the pitchblende veins running through it, there is no difficulty in admitting that the granite was capable of supplying the radio-active material of the pitchblende.

Granite, of course, consists of a variety of different minerals, which give it its mottled appearance. These minerals, there is no reason to doubt, have been formed in the successive stages of crystallisation of an originally molten mass. There is a mineral called zircon, of which the jacinths sometimes set by jewellers are a variety, which is present in very minute crystals in granite. These minute crystals of zircon have a very characteristic geometrical shape; a square prism terminated at each end by a pyramid. The fact that they have this perfect shape is a proof that they have been perfectly free to assume their natural form, and have not been hampered for want of space by other minerals surrounding them. The inference is plain that zircon has been one of the first minerals to crystallise in the consolidation of granite.

I have found that this zircon is very much richer in radium than the granite generally, though, on the other hand, it is poor compared with pitchblende. It seems clear that the minerals which crystallise first take an unfair share of the radio-active elements, leaving the rest of the magma impoverished.

In the light of this observation, Prof. Joly, of Dublin, has been enabled to explain a curious appearance which is seen when a section of the granite thin enough to be transparent is examined under the microscope. This appearance is seen in one of Prof. Joly's photographs of a minute crystal of zircon, which is embedded in a large crystal of mica. You will observe that the material surrounding the zircon for a definite distance outwards has become darkened in colour. The altered region round the speck of zircon is practically circular, and is reminiscent of a spot of grease on cloth.

Prof. Joly has pointed out that this alteration in the surrounding materials must be due to the radio-activity of the zircon. That radio-active materials are capable of producing such colorations has been known from the early days of radium. You see, for instance, projected on the screen, the image of a glass bottle, in which a radium preparation has been kept. Though originally of colourless glass, it has been stained a deep purple by long-continued action of radium.

It may, perhaps, be thought that this idea, though plausible, is no more than a guess. It is, however, much more than that. We know, from the investigations of Prof. Bragg and Mr. Kleeman, that the α particles of

[1] Discourse delivered at the Royal Institution by the Hon. R. J. Strutt, F.R.S.

radium, which constitute the most important feature of radio-active emission, are only able to penetrate a limited and definite distance into solid materials. They then lose their characteristic properties, if, indeed, they are not altogether stopped. This distance has been measured experimentally, and Prof. Joly has shown that the distance is just the same as that to which the alteration round the zircon crystals extends. Thus we have full quantitative confirmation of the theory which attributes it to radio-activity.

I will now pass from the discussion of a very minute phenomenon to the discussion of a large-scale one. It will be familiar to many of you that, in the opinion of some, at least there is reason for changing the views which have been held for two generations concerning the earth's internal heat. We know that there is, at any rate, some radium in the earth, and that radium gives out heat. Thus it cannot be disputed that some part of the earth's internal heat must be due to this cause; the only question which remains is whether this part is large or small, whether, in fact, the earth's internal heat is chiefly to be accounted for as a small remnant of the much greater internal heat which it once possessed, or whether there is enough radio-active material in the earth to supply most of the annual loss by conduction through the crust and radiation into space.

As I mentioned before, I have made a large number of determinations of the quantity of radium in the rocks of which the superficial portions of the earth are constituted. These are found to be so rich in radium that the difficulty is not so much to account for the internal heat of the earth, as determined by underground observations of temperature, but rather to understand why it is not much hotter. I have suggested, as an explanation, that this general distribution of radio-active material, which pervades the outer parts of the earth, is in reality superficial, extending only to some moderate number of miles in depth, though no doubt much deeper than the deepest mines. I am not wholly satisfied, however, of the sufficiency of this explanation. Radium, and the series of products of which it is one, are not the only radio-active materials in the earth; there is another series, of which thorium is a member, and there is good reason to suppose that thorium is present in rocks in such quantity as to add appreciably to the evolution of heat. Taking this into account, we should probably find, if we had exact data for calculation, that the thickness of rock containing radio-active material was so small that the material of the interior would somewhere have exuded, in the course of the violent dislocations and earth movements which geology reveals to us. No material, however, appears anywhere at the earth's surface which can plausibly be regarded as representative of the unknown interior if the suggested hypothesis is accepted. It cannot be denied that the subject is at present obscure. Possibly an explanation may be found by supposing that the activity of uranium may be arrested at high temperatures. We have at present no adequate experimental evidence on the subject. It is known that there is very little effect of this kind on radium. If, however, the activity of uranium were arrested at a high temperature, the supply of radium and all the other members of the series would fall off, and thus the aggregate heat production of the whole series might be greatly diminished.

I shall now pass to another branch of the subject. The investigations of Sir William Ramsay and Mr. Soddy have proved that there is continuous evolution of helium from the radium emanation. We have good reasons, into which, however, I do not propose to enter, for considering that the same is true of radio-active changes in general, at all events those in which there is an emission of radiation. Helium is probably evolved at each stage of the transformation of uranium, and at each stage of the transformation of thorium; and it results that the natural minerals and ores in which these elements are found contain a store of helium, which has accumulated in them and remains locked up in their pores.

As already mentioned, I have succeeded in determining the presence of radium in granite. Thus it becomes natural to inquire whether the corresponding amount of helium is to be found there too. Nothing of the kind had ever come under observation before, and it was, therefore, with some interest that I made the experiment. You see before you a vacuum tube of helium prepared from ordinary granite. The characteristic yellow glow will satisfy anyone acquainted with the appearance of a helium discharge of the presence of the gas.

The facility with which helium was detected in granite suggested further experimental problems. The undoubtedly radio-active elements are at present confined to uranium and thorium, and their respective families of descendants. Evidence has been produced, by myself among others, which suggests that lead and some other elements possess a feeble radio-activity of their own; but this evidence is somewhat equivocal. It seemed highly desirable to attack the question in a new way, and the idea suggested itself of looking for helium in the naturally occurring ores of all the elements, common and rare. This had indeed been done, to some extent, from quite a different point of view, by Sir William Ramsay and his coadjutors, in their first investigations on helium; but their observations were directed to finding a practical source of the gas, and were not carried out with anything approaching the minuteness required for the present purpose.

The upshot has been to prove the presence of helium in almost every mineral examined, and even in such unpromising materials as rock crystal, or common quartz sand. The quantity found in the various cases has varied very widely. In fact, minerals may be found having any helium content, from thorianite, which contains 10 cubic centimetres per gram, down to rock crystal, which contains about a ten-millionth part of that quantity.

I have here a small tube of helium obtained from clear, colourless rock crystal, and you will have no difficulty in seeing the characteristic yellow glow as before.

Are we to regard the helium in common minerals as due to a feeble radio-activity of the common elements? No doubt such an hypothesis is tempting, but it must be rejected. Radium is present everywhere in traces, and these traces are in general sufficient to account for the minute quantities of helium. This is illustrated in the table below, which gives in round numbers the actual amount of helium extracted from various minerals by heat, and the amount of helium reckoned relatively to the radium.

	Mineral	Helium present. c.mm. per kil	Helium ratio, *i.e.* ratio of helium to radium. Arbitrary scale.
Normal	Samarskite	1,500.000	14
	Hæmatite	700	9
	Galena	2	17
	Quartz	2	10
Abnormal	Beryl	33,000	954

There is reason to think, as already mentioned, that the presence of thorium would constitute another source of helium; but it is believed that this complication does not produce any appreciable effect in these cases. You will see that minerals like quartz, though they contain actually only an infinitesimal quantity of either substance, still show about the same proportion of helium to radium as the minerals which are rich in both. We may conclude that helium is connected with radium in the poor minerals as in the rich ones.

I have, however, encountered an interesting exception to this rule in the mineral beryl. Beryl is, in all essentials, the same as emerald; the latter name is kept for stones which are of a clear, deep green colour; but scientifically the distinction is of no importance. Some beryls contain enormously more helium than can be accounted for by the small traces of radium in them. Nor do they contain any appreciable quantity of other radio-active material. What view, then, can we take of the presence of helium in this mineral? It is, to me at least, difficult to believe that the gas can have been introduced from without. If not, can it have been generated from radium formerly existing in the beryl, but now exhausted? This, too, seems unlikely, for it would imply that beryls are older

than other minerals, and there is no plausibility in such a theory from the geological standpoint. My own opinion is that, in all probability, an element hitherto unknown exists in the mineral, from which the helium is generated. It may be objected that, in that case, the mineral ought to be radio-active. If, however, the radiation were emitted with less than the critical velocity, we should not be able to detect it, and nothing is known to make such an hypothesis improbable.

In conclusion, I shall be well content if I have convinced you that there is still something to be learnt from careful examination of the most commonplace materials. If there is nothing new under the sun, there are, at least, unsuspected things going on inside the earth, where the sun cannot penetrate.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

GLASGOW.—Dr. C. H. Desch, of University College, London, has been appointed university lecturer in metallurgical chemistry in the place of Dr. C. E. Fawsitt, the new professor of chemistry in the University of Sydney, New South Wales.

OXFORD.—Dr. Arthur J. Evans, F.R.S., has handed over as a free gift to the Ashmolean Museum the collection of Anglo-Saxon jewellery and other relics bequeathed to him by his father, the late Sir John Evans. With it is also a comparative series illustrating the early Teutonic art of the Continent, including specimens of Scandinavian, Frankish, Lombard, and Gothic work.

WE learn from *Science* that Colonel Oliver H. Payne, of New York, has given 10,000*l*. to the endowment fund of the University of Virginia.

WE have received a copy of the December issue of *The Record*, the magazine of the South-Western Polytechnic Institute, Chelsea. In addition to items of news about the work and play of students of the institution, the magazine contains short articles from members of the teaching staff and from students.

THE draft charter of incorporation of the University of Bristol has been issued. The following are to be the first chief officers of the new university:—Chancellor, Mr. H. O. Wills; pro-Chancellors, the Bishop of Hereford, the Right Hon. Lewis Fry, and the Right Hon. Henry Hobhouse; Vice-Chancellor, Prof. C. Lloyd Morgan, F.R.S.; and treasurer, Mr. G. A. Wills. Women are to be eligible for any office in the University and for membership of any of its constituent bodies, and all degrees and courses of study in the University are to be open to them. It has been announced that the authorities of the Bristol University College have purchased the blind asylum and its land which adjoin University College. The site thus secured will be used for the erection of part of the new university.

AN appeal is being made on behalf of the Bethnal Green Free Library Institute, which was founded thirty years ago. The institute has no endowment and no State or rate aid, but is entirely maintained by voluntary gifts. There is a lending library, a reading room, and a large reference library. Classes for instruction in various subjects are held, and lectures by Sir Robert Ball, F.R.S., Dr. Andrew Wilson, Dr. W. H. Dallinger, F.R.S., and others, have been provided. The library is entirely free. There is a debt of 250*l*. on the general fund, which the committee is anxious to clear off before the end of the year. Contributions may be sent to the treasurer, Mr. F. A. Bevan, 54 Lombard Street, E.C.

ON Wednesday of last week, December 9, the first annual dinner of old students of the Royal College of Science was held at the Criterion Restaurant, and was attended by more than a hundred old students, in addition to past and present members of the staff and members of the governing body of the Imperial College of Science and Technology, of which the college now forms a part. The chair was taken by Mr. H. G. Wells, who was a student of the college during 1884–7. The toast of the Royal College of Science was proposed by the Right Hon. A. H. D. Acland, who, after making some happy allusions to the descriptions of college life in one of Mr. Wells's books, went on to say that the governing body of the Imperial College intends to do something to foster corporate life among the students by the erection of a suitable building for a students' club. He also made an important statement as to the future of the college, indicating that the governors are fully alive to its great traditions, and that the associateship will still continue to be given as the diploma in science, just as that of the School of Mines is to be the diploma in mining. Mr. A. E. Briscoe, who responded to the toast on behalf of the old students, said that students of the college have gone all over the world, and have had much to do in bringing about that efficient teaching of scientific method which has been so marked a feature of recent educational progress. Many of the old students have made great names for themselves, and he attributed their success to the thoroughness of their training, and especially to the laboratory training they received. He hoped that under the new régime research will be the main work of the college. Subsequent speakers included Dr. H. A. Miers, principal of the University of London, who referred to the imperial character of the work of the college as a valuable feature of modern university life, and Prof. W. P. Wynne, who spoke of the debt owed by many old students to that much-abused body, the Department of Science and Art. At the conclusion of the dinner the old students present proceeded to elect a provisional committee to draw up rules for an old students' association to be submitted to a special meeting at an early date. Mr. T. L. Humberstone, 3 Selwood Place, South Kensington, will act as secretary; all old students who are desirous of becoming members are requested to communicate with him.

SOCIETIES AND ACADEMIES.

LONDON.

Royal Society, November 19.—"On the Refraction and Dispersion of Krypton and Xenon, and their Relation to those of Helium and Argon." By C. **Cuthbertson** and M. **Cuthbertson**. Communicated by Prof. F. T. Trouton, F.R.S.

The authors have determined the refraction and dispersion of krypton and xenon with larger quantities of gas than were available at the time of their first isolation. The gases were prepared in the laboratory of Sir W. Ramsay by Prof. R. B. Moore. The atomic refractive index of krypton is found to be

$$\mu = 1 + 0{\cdot}0008378\left(1 + \frac{6{\cdot}97}{\lambda^2 10^{11}}\right),$$

and that of xenon

$$\mu = 1 + 0{\cdot}0013646\left(1 + \frac{10{\cdot}14}{\lambda^2 10^{11}}\right).$$

On comparing these figures with the refractive indices of helium and argon, as determined by W. Burton, it is shown that the refractivities for infinite wave-lengths are even more nearly in the ratios of whole numbers than the earlier values. Taking the value found for argon as the standard, the divergence from integral ratios is, for krypton, 0·0 per cent.; for helium, 0·34 per cent.; and for xenon, 2·25 per cent.

If the refractive indices are expressed by means of Cauchy's formula, $\mu - 1 = a(1 + b/\lambda^2)$, it is found that, plotting a against b for the four gases examined, the relation is linear.

Owing to the untrustworthiness of the existing determinations of the dispersion of oxygen, nitrogen, and hydrogen, comparison cannot be made with other groups of elements.

Physical Society, November 27.—Dr. C. Chree, F.R.S., president, in the chair.—A graphic method of dealing with refracting surfaces: H. S. **Allen**. A graphic method is given for finding the cardinal points for combinations of coaxial refracting surfaces. The method may be applied to such cases as that of two thin lenses a finite distance apart, two refracting surfaces forming a thick lens, or to the general case of the combination of two lens systems. —An accurate method of measuring moments of inertia: